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# LOW ENERGY BEAM MEASUREMENTS USING PHIL ACCELERATOR AT LAL, COMPARISON WITH PARMELA SIMULATIONS

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## Abstract

PHIL (“PHoto-Injector at LAL”) is a new electron beam accelerator at LAL [1,2]. This accelerator is dedicated to test and characterize electron RF-guns and to deliver electron beam to users. This machine has been designed to produce and characterise low energy ( $E < 10$  MeV), small emittance ( $\varepsilon < 10 \pi \text{ mm.mrad}$ ), high brilliance electrons bunch at low repetition frequency ( $\nu < 10 \text{ Hz}$ ). The first beam has been obtained on the 4<sup>th</sup> of November 2009. The current RF-gun tested on PHIL is the AlphaX gun, a 2.5 cell S-band cavity designed by LAL for the plasma accelerator studies performed at the Strathclyde university. This paper will present the first AlphaX RF-gun characterizations performed at LAL on PHIL accelerator, and will show comparisons between measurements and PARMELA simulations.

## INTRODUCTION

One year after the first beam [1], recent upgrades on PHIL have been realized. In the last 6 months, three phosphorescent YAG:Ce screen stations, one Bergoz ICT, and a motorized slit (in the deviated beam line) have been installed. The on-line image processing treatment in the control room has been installed and tested. Thus, beam position, transverse beam size, charge and mean energy are measured with better precision. Projected 2D-emittance measurement system is under design, and longitudinal bunch length measurement will be soon available. In the following, we will first focus on the magnetic POISSON modelization of the “B3” solenoid (see Figure 1). Then, we will show the measured and simulated behaviour of the transverse beam size as a function of the “B3” solenoid current.

## ANALYSIS OF MAGNET ELEMENTS

Beam dynamic studies on PHIL have been carried out using PARMELA software [3]. The AlphaX gun [4] electrical field has been modeled using SUPERFISH [5] software. The magnetic field generated by the “B3” solenoid located at the end of the gun and “B5” located at the middle of the line (see Figure 1) have been modeled using the POISSON software [5].

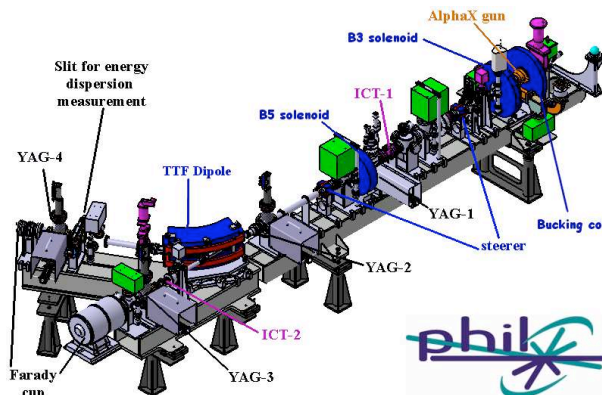


Figure 1: 3D-view of PHIL accelerator.

The modelling of the “B3” solenoid, has shown a non linearity behaviour in the  $B_{z\max}(I)$  curve [6]. This behaviour has been identified as a signature of a magnetic field saturation in the iron frame of the solenoid. Figure 2 shows the evolution of the modeled on-axis maximal longitudinal magnetic field component function of the intensity current ( $I$ ) for different solenoid iron frame types.

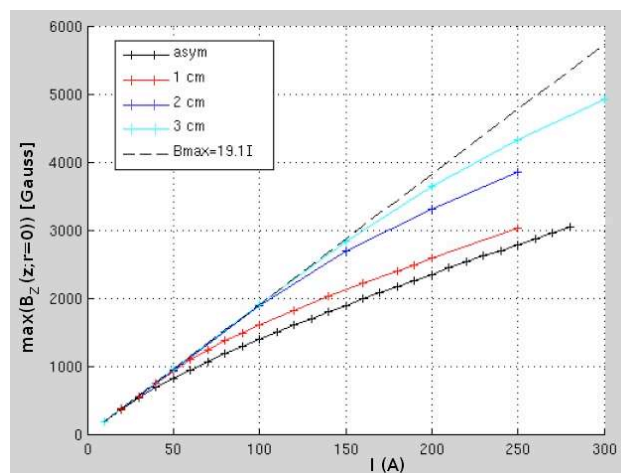


Figure 2: on-axis maximal longitudinal magnetic field component (from POISSON simulation of the “B3” solenoid function of its current. The black dashed line is the linear approximation for low  $I$  values [ $B_{\max}(\text{Gauss}) = 19.1 I (\text{A})$ ]. The black curve “asym” is the curve of the POISSON “B3” solenoid simulation. The red (resp. blue, cyan) curve is obtained with POISSON from a symmetric frame with 10 mm (resp. 20 mm, 30 mm) thick.

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The “asym” type is the modelization of the real solenoid. It is called “asym”, because the side of the solenoid frame oriented towards the photo-cathode is 5 mm thick, and the other side is 10 mm thick. The other curves shows the  $B_{z\max}(I)$  curves for symmetric frame of 10, 20 and 30 mm thick. The bigger the thickness, the later the non-linearity appears on the  $B_{z\max}(I)$  curve. At low current values, all the curves can be approximated by a linear function  $B_{z\max}(\text{Gauss})=19.1*I(\text{A})$ . This figure shows that, for a 150 A alimentation current, the real curve is 33% lower than the value given by the linear approximation. Moreover, the shape of the  $B_z(z;r=0)$  curves, for different currents, are not homothetics [6]; and a specific curve has to be used for each current intensity (see Figure 3). At the opposite, the “B5” solenoid which is symmetric, has a  $B_{z\max}(I)$  curve which is linear, and does not need such specific treatment in PARMELA simulation.

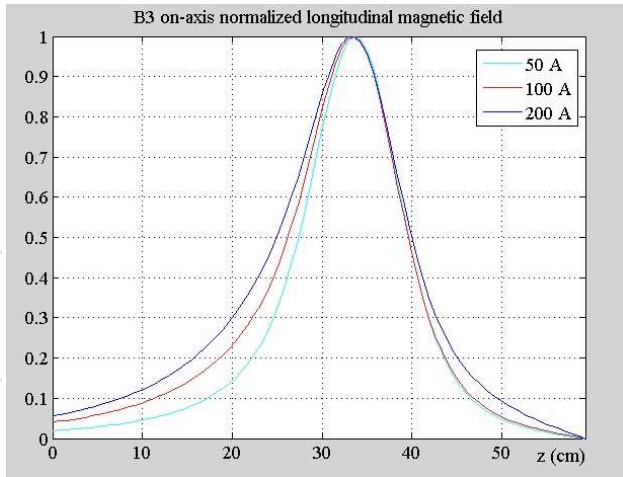


Figure 3: “B3” solenoid normalized on-axis longitudinal magnetic field component for different alimentation current ( $I=50, 100$  and  $200$  A).

To take into account this specificity into PARMELA, the “B3” solenoid has been modelized using the “COIL” option, which approximates the input (real or simulated)  $B_z(z;r=0)$  field component by a linear superposition of Helmholtz coils magnetic fields :

$$B_z^{\text{INPUT}}(z;r=0) = \sum_{\text{COIL}=1}^{\text{COIL}=N} B_z^{\text{COIL}}(z;r=0)$$

where

$$B_z^{\text{COIL}}(z;r=0) = \frac{\mu * I_{\text{COIL}} * r_{\text{COIL}}^2}{2 * (r_{\text{COIL}}^2 + (z - z_{\text{COIL}})^2)^{3/2}}$$

is the magnetic on-axis longitudinal field component created by one COIL element (“ $\mu$ ” is the permeability constant =  $4\pi \cdot 10^{-7}$  T.m/A). Each COIL element is defined

by its current ( $I_{\text{COIL}}$ ), its radius ( $r_{\text{COIL}}$ ) and its longitudinal position ( $z_{\text{COIL}}$ ). In order to create these linear superposition for each input  $B_z(z;r=0)$  curves, a code has been written in MATLAB. This code fixed a collection of Helmholtz coils whose magnetic fields superposition describe the input  $B_z$  field with a good precision in less than a minute. The number, the current, the radius and the position of COIL elements are determined for each input field by the code itself. Figure 4 shows the input field (from POISSON) and the output of the MATLAB code for the “B3” solenoid excited with a 145 A current. In this example, the input field is reconstructed using 58 COILS elements.

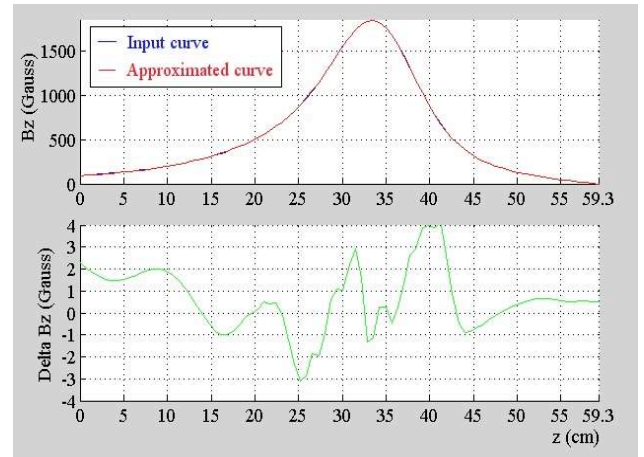


Figure 4: POISSON and “COIL approximation” of the on-axis longitudinal magnetic field of “B3” solenoid excited with a 145 A current. The upper figure shows the total magnetic  $B_z(z;r=0)$  field from POISSON and from the MATLAB code. The lower figure shows the difference between the two curves.

## TRANSVERSE BEAM SIZE MEASUREMENT AND COMPARISON WITH PARMELA

Two shifts have been dedicated to transverse beam size, solenoid scan and charge measurement. The transverse beam size has been evaluated using the first YAG:Ce screen station (YAG-1 of Figure 1, located at 1925 mm from the photocathode) equipped with a CCD and an achromatic doublet lenses. The mean and rms values estimation of the horizontal and vertical beam sizes have been done after background current subtraction and gaussian fit on projected images as describes in [1]. The solenoid scan has been performed using the “B3” magnetic element. The charge measurement is carried out with a Faraday cup located at the end of the direct beam line (Figure 1). The charge was measured to be 85 pC on the first shift and 200 pC in the second. The laser transverse rms beam size was estimated to be 0.5 mm in both shifts. The maximal longitudinal magnetic field amplitude of the “B3” solenoid has been varied from approximately 200 to 2200 Gauss (i.e : 10 to 180 A for

Sources and Medium Energy Accelerators

Accel/Storage Rings 08: Linear Accelerators

the alimentation current). Those two experimental results have been compared with PARMELA simulations, in which the description of the laser sizes and the accelerating gradient inside the cavity are in the same order of magnitude of the measurements. The comparison shows that the experimental transverse beam size measurement can be approached by PARMELA simulations. Figure 5 (resp. 6) present the comparison between measurements and PARMELA simulations for the first and second shift where the accelerating gradient was respectively 67 MV/m and 75 MV/m.

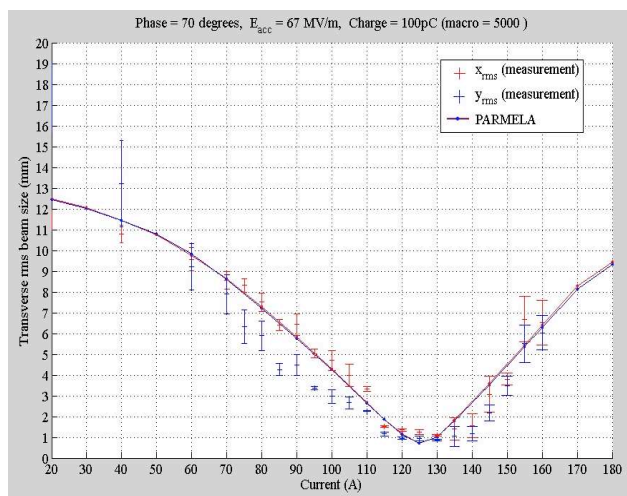


Figure 5: first “B3” solenoid-scan (1<sup>th</sup> July 2010). Comparison between experience and PARMELA simulation (charge at the photocathode =100 pC, transverse rms laser beam size = 0.9 mm, cut at 5 mm; and laser pulse duration of 3.6 ps cut at 10 ps. The peak electrical field is 67 MV/m).

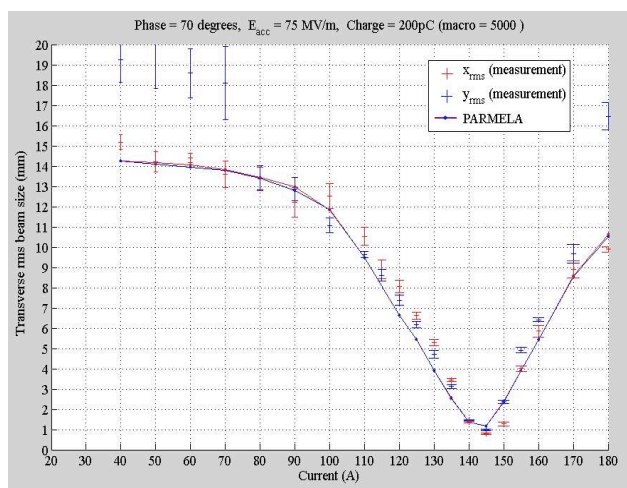


Figure 6: Second B3 solenoid-scan (16<sup>th</sup> July 2010). Comparison between measurements and PARMELA simulation (charge at the photocathode =200 pC, transverse rms laser beam size = 2 mm, cut at 5 mm; and laser pulse duration of 3.6 ps cut at 10 ps. The peak electrical field is 75 MV/m).

The average total beam energy of the PARMELA computation is 4.56 (and 5.12) MeV for a 67 (and 75) MV/m accelerating field. During the second shift, an energy measurement has been carried out using the TTF dipole magnet (see Figure 1) and the slit located in the deviated beam line. The average total energy of the beam has been estimated to be 5.2 MeV. Thus, the average kinetic energy beam from PARMELA is 1.7% lower than the measured one.

The horizontal and vertical projected emittances from PARMELA simulations are presented in table 1. These values are dependant of the transverse laser beam size at the photocathode (0.9 and 2 mm rms).

Table 1: x and y normalized emittance (mm.mrad) given by the PARMELA simulation at the location of the YAG:Ce.

	$\epsilon_{X\_NORM}$	$\epsilon_{Y\_NORM}$
First scan (for I=125 A)	10	10
Second scan (for I=145 A)	38	37

## CONCLUSION

In this paper, we highlight a non-linearity behaviour in the  $B_{z_{max}}(I)$  curve of the “B3” solenoid, which is identified as a signature of the magnetic field saturation in the iron frame of the solenoid. Using this specificity in PARMELA simulations, the firsts solenoid scans measured on PHIL are in good agreement with simulations. The simulated average kinetic energy beam is 1.7% lower than the measured one. The current minimal transverse beam size achievable is 1 mm rms.

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